Cross-Hair System Performance Requirements

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Abstract

This document describes the geant simulations run to determine acceptable alignment cross hair specifications, and what the ultimate signal to background expected for special alignment runs. Also described is the response of beam loss monitors to a scan of the neck of horn 1.

1 Introduction

In order to know the location of the horns, one can mount cross-hairs on the ends and scan them with the proton beam, and measure the increase in flux in nearby beam loss monitors. Initial studies of the alignment system performance were shown in NUMI-B-796 by Adam Para; the study reported here uses the full geant beamline simulation, but modified to resemble what the beam will be like for these special alignment runs. Also of interest is the response of the beam loss monitors to scans of the neck of horn 1. Because of the geometry of the beamline, the neck of horn 2 cannot be scanned once horn 1 is in place.

2 Strategy

As described in NUMI-B-796, cross-hairs can be added to the horns to provide a precise fiducial whose position can be measured in situ by scanning the proton beam (in the absence of a target or baffle) across the cross-hairs. If there is a BLM downstream of the crosshairs, and one can scan one set of wires without hitting the other, then one sees an independent increase in the flux measured by the BLM as the proton beam hits the cross hairs. The proton beam and cross hairs will have comparable widths, so the resulting "peaking" in the flux at the BLM will be significantly wider than the wire itself. Nevertheless, this can provide a precise measurement of the location of the cross-hairs.

By putting one at both the upstream and downstream ends of horn 2, in principle one can measure both the position and angle of horn 2 in the vertical and horizontal direction. However, because of the target one cannot put a crosshair upstream of horn 1. But, by scanning over the downstream cross hair and the neck of the horn, one could have the necessary constraints from which to verify the position and angle of horn 1.

A picture of the beamline with the horns and crosshairs is shown in figure 2.

3 Modifications to Standard Beamline Geometry

The cross hairs themselves are put into geant as "blocks" of aluminum that are 1mm wide, 6 or 18mm long, and long enough to span across the entire horn (although this dimension won't matter ultimately, since the scans will all take place near the beam axis. The cross hairs have the following dimensions, listed in table 3.

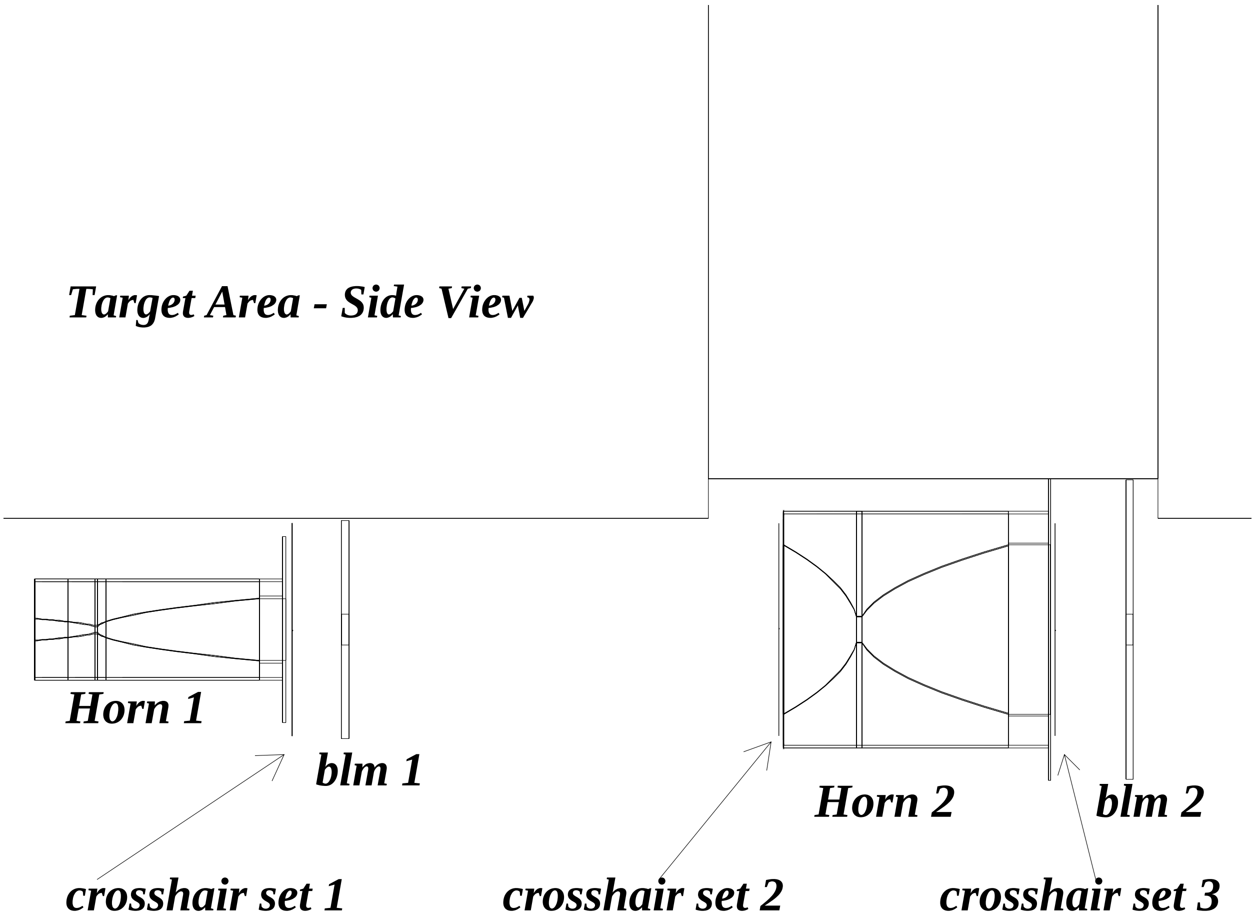

Figure 1: Schematic of the beamline showing the two horns, the three sets of crosshairs, and the two locations for beam loss monitors.

The monitors are simply circular shields that geant records passing through, and are located downstream of horns 1 and 2, at the locations 4.099m and 14.573m, and in order to fit in the chase and be centered on the beamline, and not see the uninteracted proton spot, have inner and outer radii of 5cm and 35cm, respectively.

In order to scan the wires effectively, one must remove the baffle and the target from the beamline–otherwise the proton beam will hit either of those things before it ever reaches the alignment cross hairs.

In reality, the proton beam leaves the vacuum region of the beamline 21 feet upstream of Horn 1. At that point it starts passing through air, and it can interact with that air. So the geant code must be modified first of all so that the proton beam starts at a z location of -6.75m, and the "target area" must be defined starting that far upstream of the target.

Third of all, there are flanges on the ends of both horn 1 and horn 2, and a stripline running to each of the horns from the top of the chase. In the version 14 of geant, these flanges and stripline were not yet specified, but they will contribute a fair amount of the background at the BLM's, so they were included here. There is assumed to be no current running through either the end flanges or the aluminum of the horns themselves. The horn 1 flange consists of two cylinders and a flat toroid: the cylinders are 31.1cm long, and about 1cm thick, one with an inner diameter of 19.68cm, and the other with an inner diameter of 15.33cm. The endcap of the horn that runs from the inner conductor of the horn to the outer conductor is approximated by a disk with a hole in the center, where the disk is 3.81cm thick. The horn 2 flange is similar in construction, only the cylinders are 53.48cm long, with inner radii of 27.11cm and 38.87cm, and are 0.64cm and 0.87cm thick, respectively. The endcap of horn 2 is 3.175cm thick.

The parameters of the proton beam must be changed to account for the fact that now the proton beam is starting farther upstream from the nominal location (either in front of the target, or in front of the baffle). The nominal proton spot size is $1mm \times 1mm$ at the target, and the divergence is 0.9×10^{-4} in both the vertical and horizontal directions. This would produce one sigma spot sizes at the three sets of cross hairs of 1.056,1.37, and 1.49mm. To get those spot sizes, new initial beam sizes and divergences were chosen, as shown in table 3. Also, to scan the horn neck, which is located approximately 82cm downstream of the front face of horn 2, the spot size and divergence must also be changed.

Finally, the scan of either the cross hairs or the horn 1 neck will be done using the vertical and horizontal trim magnets which are located far upstream of where the air starts, and where the proton beam starts in the geant code. Specifically, the vertical and horizontal trim centers are located 22.89m and 23.35m upstream of the front face of horn 1. So in order to hit a cross-hair which is located 3.4m downstream and 2.5mm off of that front face of horn 1, the proton beam has to have a slope of 9.33×10^{-5} and an initial displacement of 1.55mm when it first enters the air volume, which is only 6.75m upstream of the front face

Table 1: Characteristics of the three sets of cross-hairs according to GEANT

Characteristic	Horn 1		Horn 2 Upstream		Horn 2 Downstream	
center in x (cm)	-0.25	0.0	0.25	0.0	-0.25	0.0
center in y (cm)	0.0	-0.25	0.0	0.25	0.0	-0.25
upstream edge z(m)	3.434	3.440	9.922	9.94	13.624	13.63
Length (cm)	0.6	0.6	1.8	1.8	0.6	0.6
Thickness in x (cm)	0.1	34	0.1	34	0.1	34
Thickness in y (cm)	34	.1	34	0.1	34	0.1

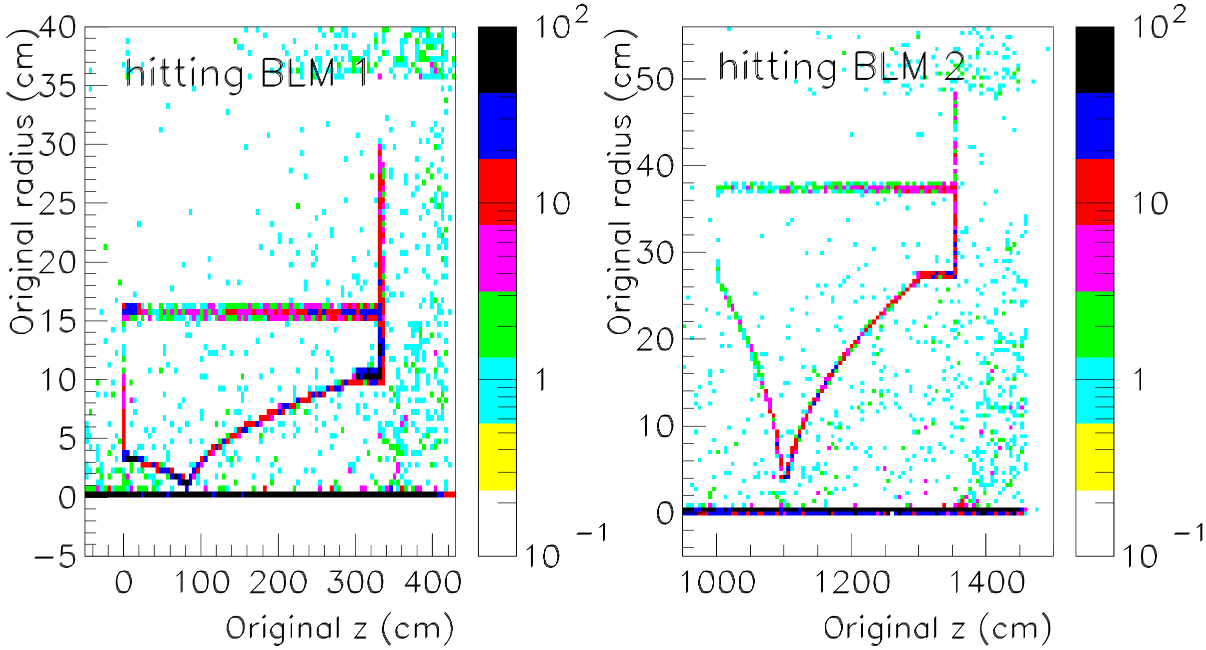

Figure 2: Radius and distance along beamline of the origin of particles which reach the monitors, which start at a radius of 5cm from the beam. Not shown is the peak at 10^4 where the proton beam hits the cross-hairs.

of horn 1. Similar slopes and offets are required to hit the other locations.

4 Results for a Cross-hair Scan

Figure 3 shows roughly where particles interact to give signals in the beam loss monitors. The outlines of the horn conductors and flanges are clearly seen. For the jobs from which these plots are made, the proton beam is aimed direcly at the cross-hair, which in each case is located in the lower right side of the plot (the spray can be seen leaving the wire as well). There are about 10^4 particles originating from the wire itself (for 5×10^5 protons in the beamline), but to see the rest of the structure in the plot bins above 10^2 are blacked out.

Figure 4 shows the results of this study, namely, what is the flux in the BLM as a function of where the proton beam is relative to the crosshairs. For the crosshairs that are located close to the BLM's themselves, namely the downstream cross hairs, there is about a 30% rise in flux as the beam goes from 2.5cm away from the wire to centered on the wire (figure 4(a) and (b)). This increase is roughly constant as a function of the distance of the BLM from the beam axis. However, for the cross hair which is upstream of horn 2, scanning it only gives a 10% increase in the flux if the wire is 6mm long (figure 4(c)). By increasing

Table 2: Proton beam parameters for the right spot sizes at different sets of cross hairs.

Set of Cross Hairs	Final Spot Size	Initial Spot Size	Beam Divergence
Downstream of Horn 1	1.056	0.952	0.45×10^{-4}
Upstream of Horn 2	1.37	1.146	0.45×10^{-4}
Downstream of Horn 2	1.49	1.176	0.45×10^{-4}
Horn 1 Neck	1.07	1.006	0.45×10^{-4}

the crosshair thickness to 1.8mm (figure 4(d)) this increase goes up to the same size as that for the other crosshairs.

Figure 4 shows on a linear scale what scans of the three sets of cross hairs would provide, as well as fits to gaussian distributions. By fitting to a constant plus a gaussian distribution, one can characterize the response of this alignment system. The widths are approcimately 1mm for scans of the wires after horn 1 and before horn 2 (recall that those before horn 2 are three times the length of the others), and the width for the last set of horns is about 1.7mm. The ratio of signal to noise when the center of the proton beam is hitting the center of the crosshair is 30 to 40 %.

As can be seen in figure 4, the response of this alignment system is not a function of the distance one puts the beam loss monitor from the center of the beamline. For BLM's at radii above about 15cm the signal to noise ratio and the width of the gaussian are roughly constant.

Finally, it is important to consider what the eventual position uncertainty would be for a scan, given that the beam loss monitors will have some expected systematic uncertainty on their measurements. Assuming the shapes that are depicted in figure 4 are sampled by a scan of 7 points between -3.5mm and 2.5mm (where the crosshairs are assumed to be at "0"), (i.e. every 0.5mm), then with 5 to 10% uncertainties on the BLM readbacks, one can achieve an uncertainty of less than a half a millimeter. Figure 4 shows what the uncertainty on the mean would be, when one fits 7 points with the associated shapes, assuming that the 7 readings were randomized with errors listed on the horizontal axis. If the readings are not randomized but the predicted scan fluxes are simply fit, the error given is indicated by a line. Although the absolute response of the BLM is not going to be known within 5-10%, it is unlikely that it would drift during the period of the scan by nearly that much. Certainly the response of the BLM divided by the protons on target (given by a toroid measurement) should be constant to better than 10% over the scan period.

The alignment of the multiwires that monitor the proton beam is 0.1mm for the position and $15\mu rad$ for the angle between the two multiwires, which are themselves separated by 12m, upstream of the target. These alignment uncertainties would result in a 0.5,0.15, and 0.20mm uncertainty at each of the three sets of crosshairs, respectively. So while a 7 point scan would result in a positioning accuracy of slightly worse than the proton beam alignment, it would be quite adequate to serve as an in situ cross-check of the optical alignment. Figure 4 also shows how large this alignment uncertainty is for the three sets of cross hairs. For a BLM uncertainty of about 3 to 4%, the uncertainties from the two measurements would be comparable.

5 Results for a Horn Neck Scan

Figure 5 shows the fluxes at the upstream BLM as the proton beam is scanned across the neck of horn 1. The turnon of the flux as the beam starts to hit the horn is extremely fast, and with a few points in the scan one could certainly position the heck of horn 1 to better than a half a milimeter. Note here that the "signal to noise", when hitting the edge of the horn 1 neck, is about 10 to 1, even at high radii. The alignment due to a scan could easily be better than a half milimeter, which is comparable to the alignment uncertainty that would be due to the primary beam instrumentation alignment.

6 Effects on Neutrino Event rates

Although the extra amount of material in the beam is very small, it is worthwhile to verify that there will not be any noticable change in either the far detector event rate or the ratio of near/far events. It is likely that the beam loss monitors would be pulled back behind the chase shielding during normal running, so the most important effect is that of the cross hair material alone.

In order to see any sizeable effect in GEANT with 1CPU day of statistics, it was necessary to make the crosshairs considerably thicker than they need to be. Figure 6 shows the ratios of the near and far detector fluxes from the addition of cross-hairs that are factors of 10 and 25 longer than the lengths specified above–but the same size in the dimensions transverse to the beam. The reduction in neutrino flux below the peak for these cases implies that there is less than a 0.1% loss in neutrino flux for the crosshairs described above (that are 6mm thick or 1.8cm thick).

7 Conclusions

By placing sets of crosshairs downstream of horns 1 and 2, and upstream of horn 2, and two beam loss monitors (one after horn 1 and one after horn 2), one can scan the proton beam across the cross hairs and measure their positions. During the scan it is assumed that the horns will not be pulsed, and the target and baffle will be raised far from their nominal position.

For crosshairs that are 1mm wide by 6mm long, (downstream of horns 1 and 2), and crosshairs that are 1mm wide by 18mm long (upstream of horn), the signal to noise ratio as the cross hairs are scanned is 0.3-0.4 to 1. Assuming that the response of the beam loss monitors varies by 5% or less during a scan, then a 7 point scan can result in position uncertainty of better than 0.5mm, which is only slightly worse than the uncertainty on the optical alignment at those locations. By scanning the neck of horn 1 one can obtain an additional position measurement, only for that scan the signal to noise ratio is roughly 10 to 1. The resulting position uncertainty could again be less than 0.5mm. These signal to noise ratios are constant as a function of distance of the beam loss monitors from the beamline axis, for distances from 15 to 35cm.

Furthermore, the resulting loss of neutrino flux due to the presence of this extra material in the beam is negligibly small. For crosshairs that are 25 times longer than those specified above, the neutrino flux loss is about 2% below 5GeV, implying that for the nominal configuration, the neutrino flux loss would be less than 0.1%.

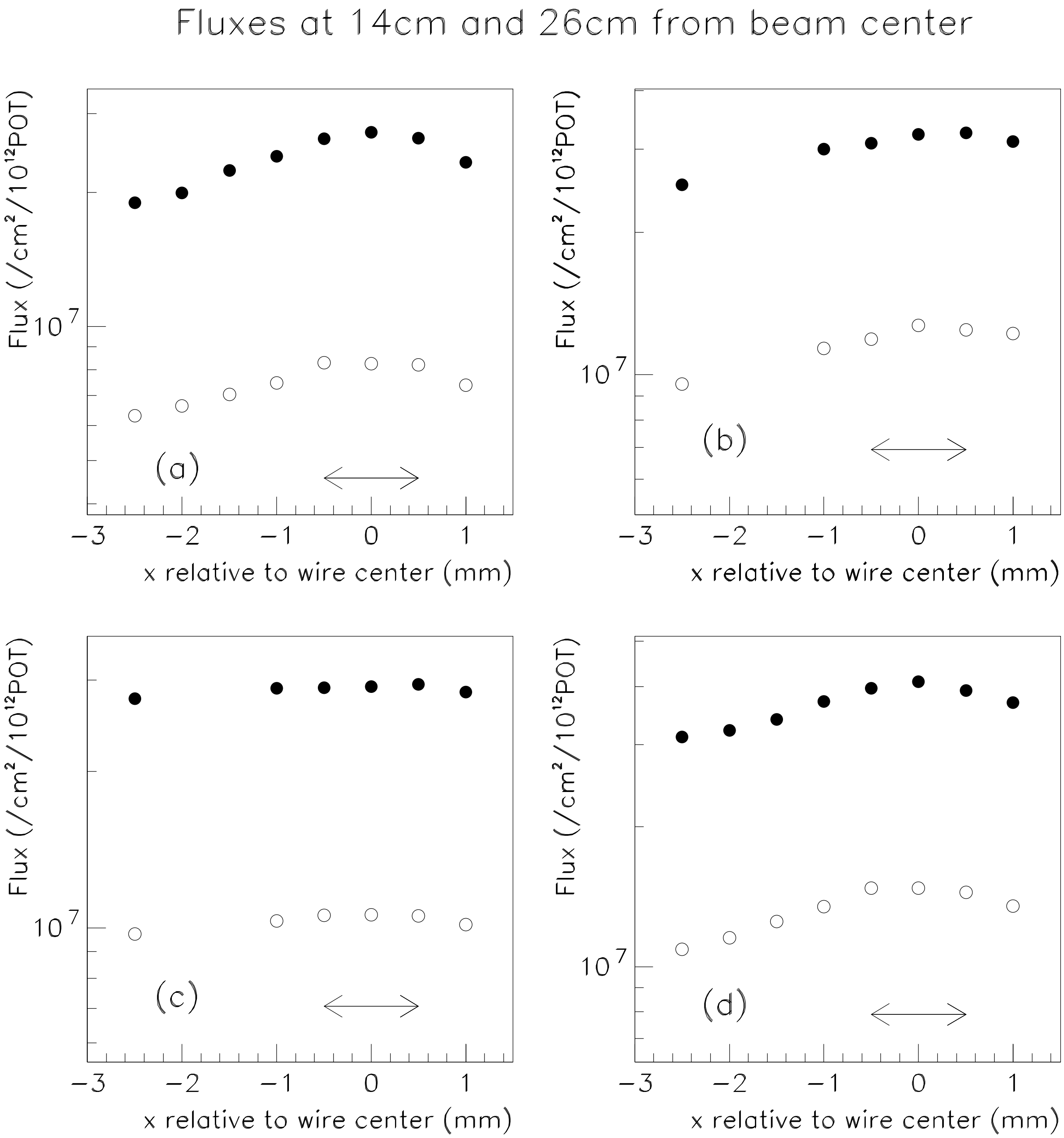

Figure 3: Fluxes as a function of distance between where the proton beam is aimed and the cross-hair position. (a) Aim at wire at downstream end of horn 1 (b) aim at wire at downstream end of horn 2 (c) aim at wire at upstream end of horn 2, with 6mm wire, (d) same as (c), but with the wire 18mm thick instead of 6mm thick.

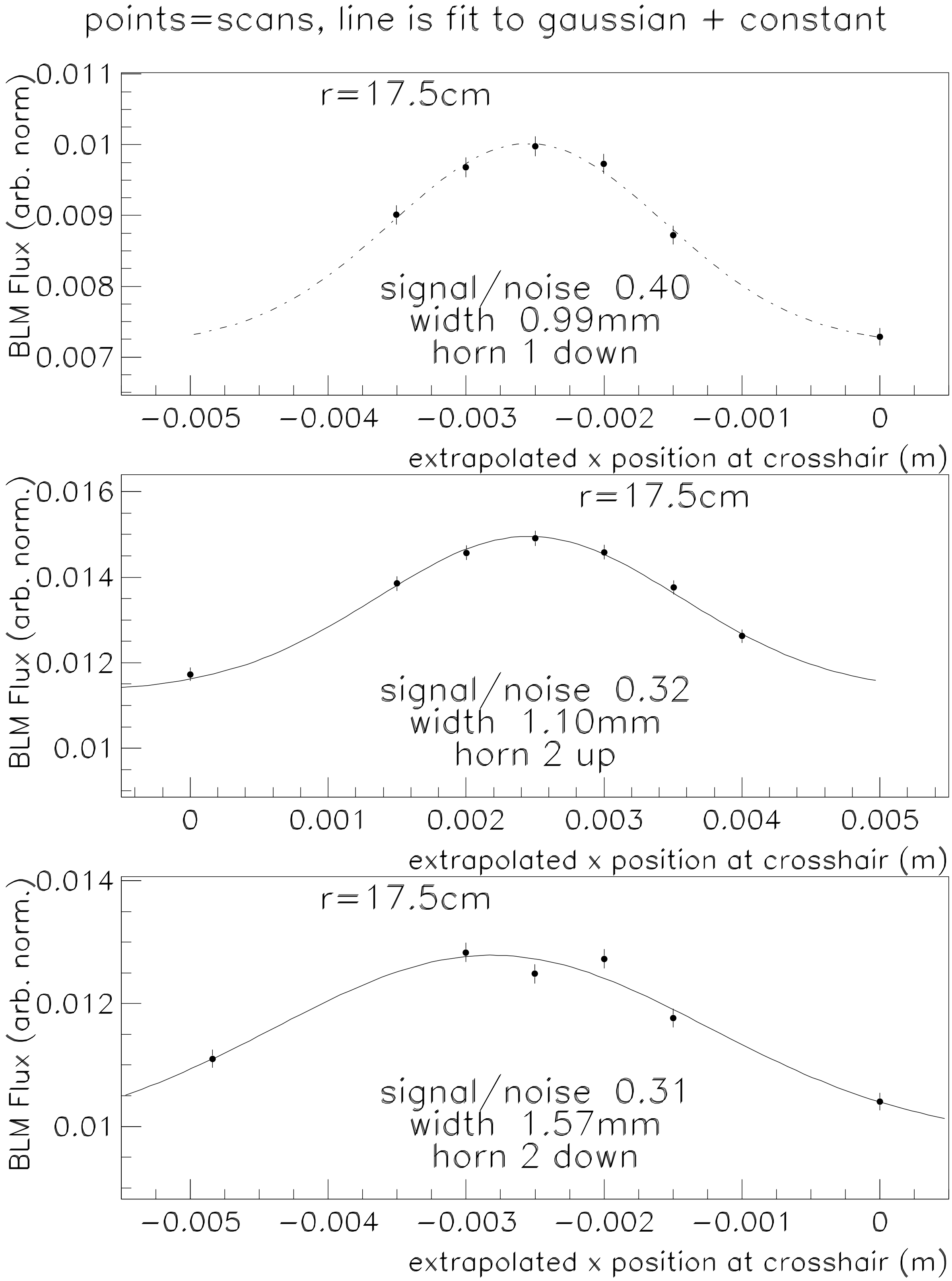

Figure 4: Results from a proton beam scan across the three sets of crosshairs, for BLM's located 16cm away from the beamline axis. The crosshairs are 6mm long, except for those upstream of horn 2, which are 18mm long.

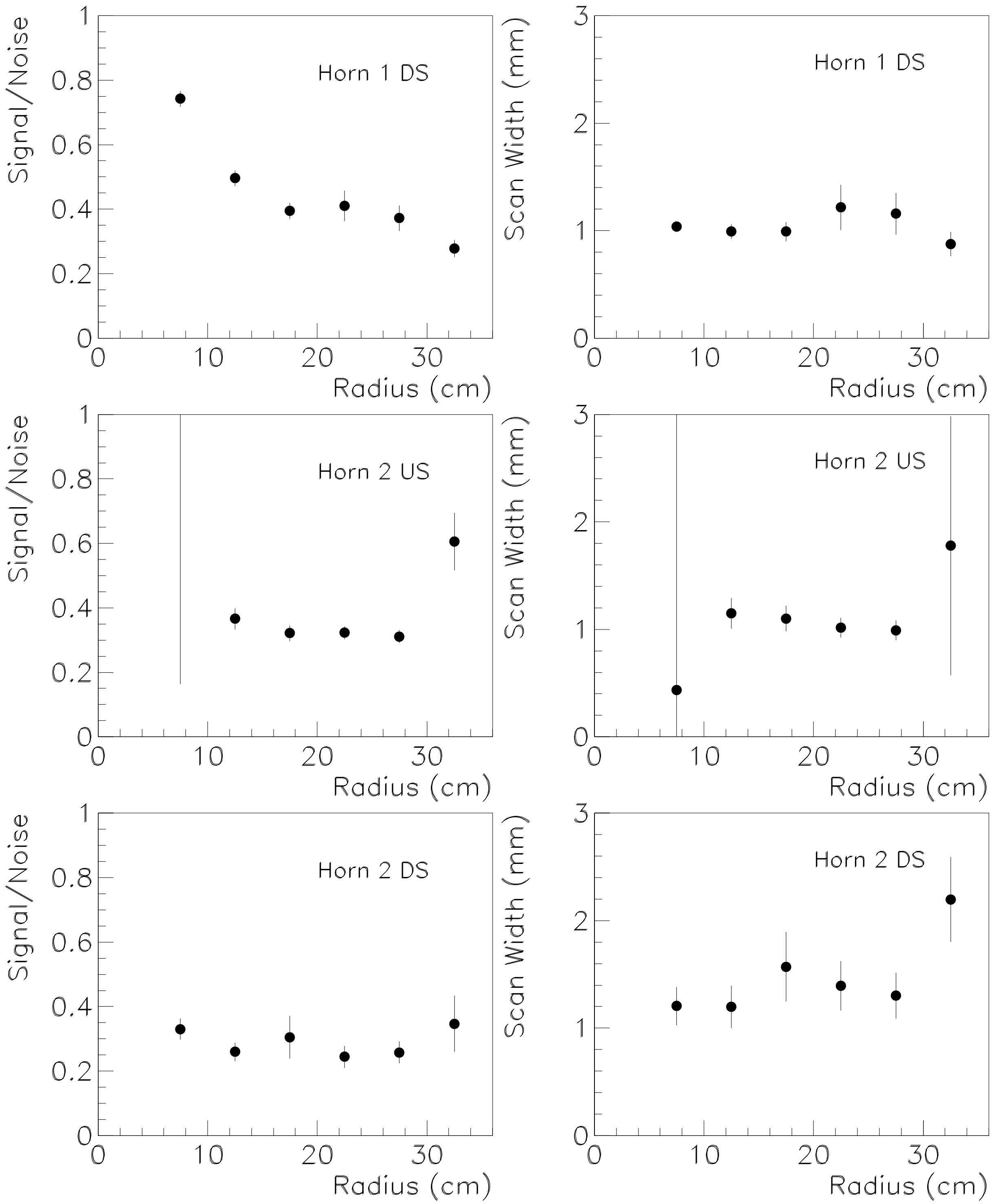

Figure 5: Parameters that describe the scan: Signal to noise ratio (left) and the width of the gaussian signal (right) as a function of the distance between the BLM and the beamline axis.

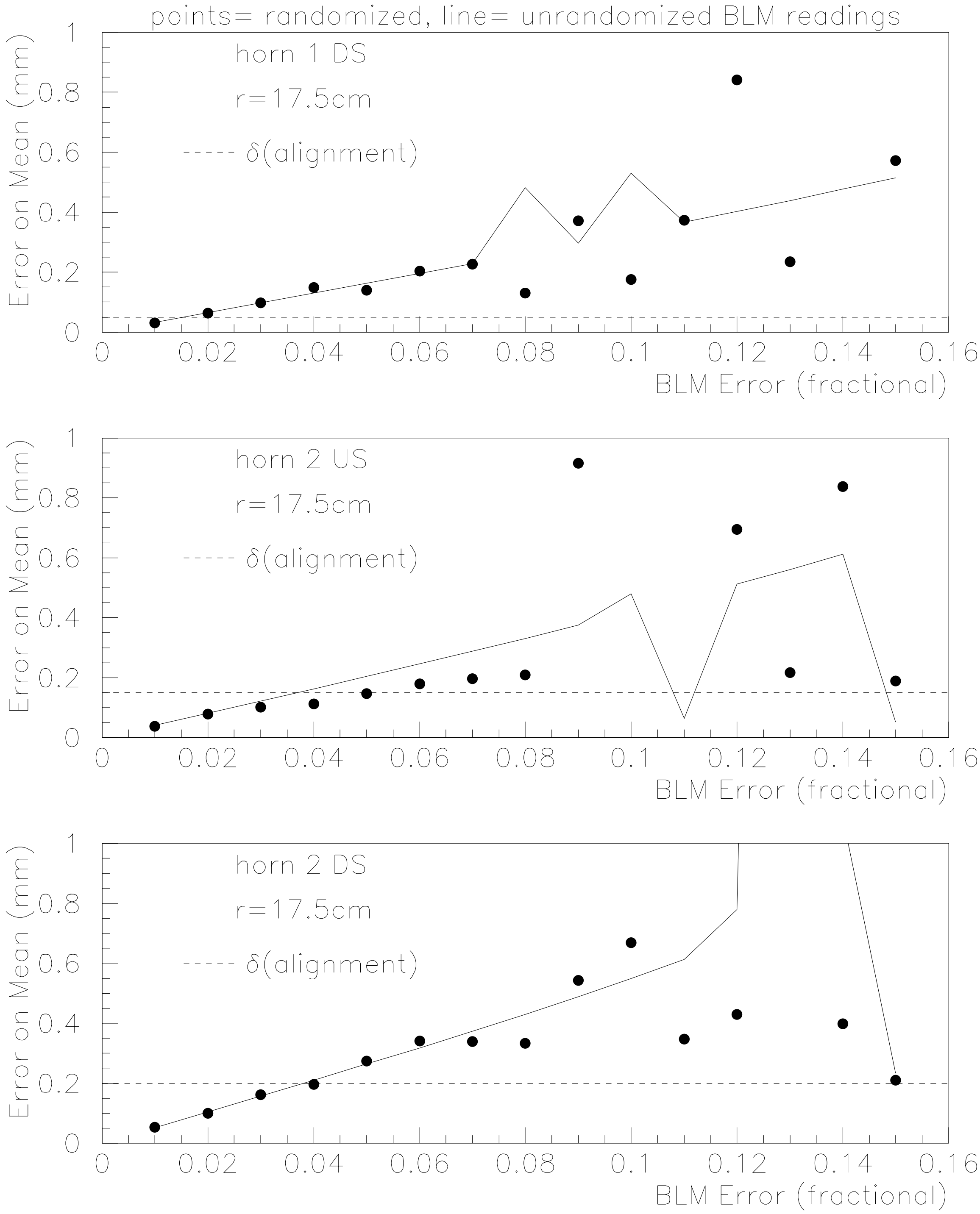

Figure 6: Error on the cross hair position that would result from an uncertainty on the response of the beam loss monitors. The response is randomized by the amount indicated on the horizontal axis, and each scan consists of 7 points which are separated by about 0.5mm.

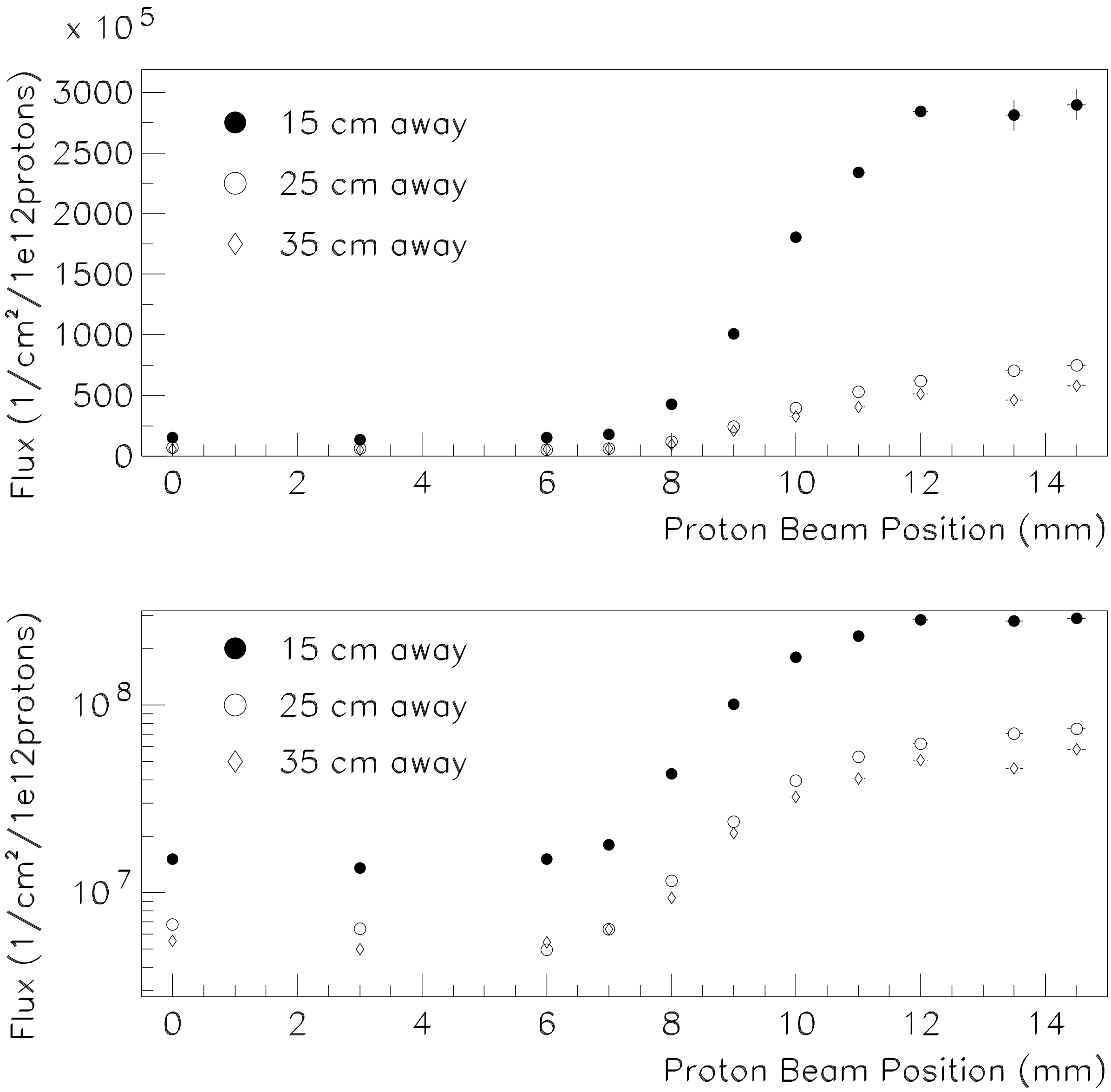

Figure 7: Fluxes per 10^{12} protons at the upstream BLM as a function of distance between where the proton beam is aimed and the neck of horn 1 (the neck starts at 9.0mm and extends to 13.5mm on this scale).

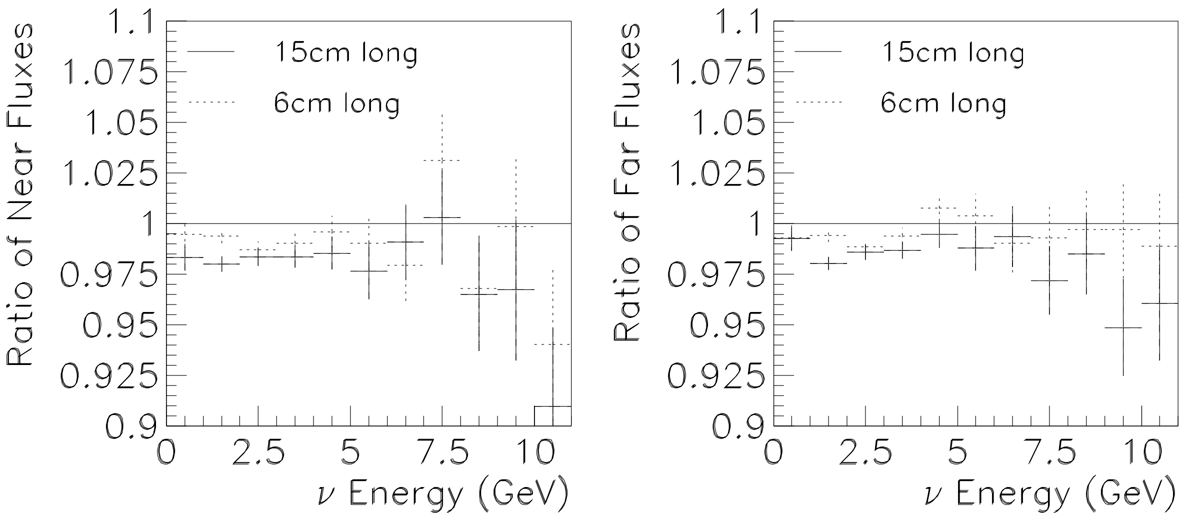

Figure 8: Ratios of near (left) and far (right) fluxes for the case of cross hairs that are 15cm long or 6cm long–compared to no cross hairs. The crosshairs described in earlier sections were 6mm long.